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LIQUID MODEL STUDIES OF THE BASE SURGE

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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Prepared by:
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ABSTRACT: When a constrained column of dense liquid standing on the bottom of a tank of water is released suddenly, it sinks and flows outward radially along the bottom. This action simulates the early motion of the base surge from shallow underwater explosions. Such liquid model experiments are described, scaling laws are derived, and comparisons with CROSSROADS Baker are made. It is estimated that between 100,000 and 130,000 tons of water in the Baker column contributed to the surge, that the column height was between 3500 and 4000 feet, and that the column density was between 1.4 and 1.6 times that of air.

EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, SILVER SPRING, MARYLAND

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LIQUID MODEL STUDIES OF THE BASE SURGE

This report is a brief compilation of some unclassified work done at the Naval Ordnance Laboratory in 1950-1954 on a simple liquid model of the base surge formed by shallow underwater explosions. This work has been reported previously as sections of several classified documents; it is reissued here in unclassified form because of current interest in liquid models both inside and outside the Laboratory.

The original work was done for the Armed Forces Special Weapons Project, under Task NOL-152, and was classified because of its applicability to the CROSSROADS Baker shot. The pertinent data have since been declassified; see AEC-DOD Classification Guide, OC Doc-56, July 1958.

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By direction

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LIQUID MODEL STUDIES OF THE BASE SURGE

I. MECHANISM FOR BASE SURGE FORMATION[a]

by

J. S. Coles*, Brown University, and G. A. Young

The column that rises immediately following a very shallow underwater explosion seems to consist of a roughly cylindrical cloud of small droplets with a jet of liquid water of relatively small diameter rising above its center. In most cases the central jet is obscured; in nuclear explosions the jet is absent and the column is believed to be hollow.

During its rise the column entrains a portion of the surrounding air, so that the column eventually drops in the manner of a single dense fluid - a phenomenon known as "bulk subsidence".

The generally accepted concept of the mechanism of surge formation is that the falling suspension of water in air spreads out radially at the water surface as the base surge. The heavier liquid particles drop back into the water surface, while the smaller are carried horizontally outward by the flow. The base surge may be described as a dense fog or cloud, an aerosol, or a density current containing suspended liquid and solid particles. Its irregular turbulent appearance may be attributed to the inhomogeneous nature of the falling column, the falling of large masses of water and solid material from above into the surge, and the instability produced by the flow of cold air over warm water.

The initial radial propagation of the surge cloud depends chiefly on gravitational effects. The intermediate stages are probably appreciably influenced by drag due to mixing, and the final dissipatory stage is probably governed almost entirely by meteorological conditions. It is the initial radial propagation which was studied by the liquid models.

Figure 1 shows two views of the CROSSROADS Baker base surge at early times. This was used as the prototype for the liquid model studies.

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a. This section is excerpted from Reference (1). See Page 22.
*Now at Bowdoin College.

(a) 15 SEC

SURGE RADIUS = 1800 FT
SURGE HEIGHT = 400 FT

(b) 41 SEC

SURGE RADIUS = 3600 FT
SURGE HEIGHT = 650 FT

FIG. 1 BASE SURGE FORMATION (TEST BAKER)

II. MODEL LAWS IN RELATION TO SCALING OF THE BASE SURGE PHENOMENON[b]

by

A. B. Arons, Amherst College

1. Introduction. The discussion given below consists of a development of the fundamental model laws and their application to the description and prediction of base surge effects. This is not a new contribution to the theory of models but is simply an elementary development of pertinent ideas which, when thus assembled in one report, may prove useful to workers in the field and may help others more readily to use and interpret the results being reported. More detailed discussion of model laws and of hydraulic models may be found in References (3) and (4) upon which this section is largely based.

2. Elementary Model Laws for Geometrically Similar Model and Prototype. "Geometrical similarity" means similarity of form, i.e., two objects are geometrically similar if the ratios of all homologous dimensions are equal. The term "kinematic similarity" denotes similarity of motion, i.e., the paths of homologous particles are geometrically similar, and the ratios of the velocities of the various homologous particles involved in the motion are equal. "Dynamic similarity" implies similiarity of masses and forces, i.e., two-motion occurrences are dynamically similar if they are kinematically similar, if the ratio of masses of the various homologous particles are equal, and if the ratios of homologous forces which affect the motion of the homologous particles are equal.

We adopt the following notation, the subscripts m and p denoting model and prototype respectively:

x_m, x_p	homologous linear dimensions.
t_m, t_p	homologous time intervals.
m_m, m_p	homologous mass particles in corresponding positions.
F_m, F_p	homologous mass accelerating forces.
ρ_m, ρ_p	densities of homologous mass particles.

b. This section is taken from Reference (2).

Then for geometrical similarity of model and prototype

$$\frac{x_m}{x_p} = x_r ,$$

a constant ratio for all homologous linear dimensions.

For kinematic similarity the ratio of homologous time intervals required for any two homologous particles to travel similar paths must be constant throughout the system:

$$\frac{t_m}{t_p} = t_r$$

Similarly, for dynamic similarity:

$$\frac{m_m}{m_p} = m_r ; \frac{F_m}{F_p} = F_r$$

From dimensional considerations it then follows that:

(a) the ratio of homologous volumes: $V_r = x_r^3$

(b) the ratio of velocities of homologous particles at corresponding positions: $v_r = \frac{x_r}{t_r}$

(c) the ratio of accelerations of homologous particles at corresponding positions: $a_r = \frac{x_r}{t_r^2}$

Both model and prototype must satisfy Newton's second law:

$$F_m = m_m a_m ; F_p = m_p a_p$$

Therefore:

$$F_r = m_r a_r = \rho_r x_r^3 \frac{x_r}{t_r^2} \tag{1}$$

In addition, other conditions must be satisfied, depending upon the nature and relative importance of the other driving

forces. Perfect similarity is rarely attainable in the model because it is generally impossible to satisfy all the additional restrictions, but simple scaling laws may be derived for situations in which one particular kind of force is dominant.

The Froude Law. For the case in which the force of gravity is the dominant one causing motion in both model and prototype, the gravitational forces acting on homologous mass particles are:

$$F_m = \rho_m V_m g_m \; ; \; F_p = \rho_p V_p g_p$$

and

$$F_r = \rho_r x_r^3 g_r \tag{2}$$

where g_r is the ratio of gravitational accelerations in the model and prototype; its magnitude is usually unity, but it will be retained here as an algebraic symbol for generality.

To satisfy both (1) and (2) it is necessary that:

$$\rho_r x_r^3 \frac{x_r}{t_r^2} = \rho_r x_r^3 g_r \, ,$$

from which

$$t_r = \left(\frac{x_r}{g_r} \right)^{1/2} \tag{3}$$

When $g_r = 1$,

$$t_r = (x_r)^{1/2} \tag{4}$$

indicating that the ratio of homologous time intervals will be equal to the square root of the length scale when gravitational effects are dominant. This is the basis of "Froude scaling".

Since the ratio of velocities of homologous particles:

$$v_r = \frac{x_r}{t_r} \, ,$$

equation (3) may be written in another form:

$$v_r = (x_r g_r)^{1/2} \tag{5}$$

or, alternatively:

$$\frac{v_m^{\ 2}}{x_m g_m} = \frac{v_p^{\ 2}}{x_p g_p} \tag{6}$$

Equation (6) represents what is perhaps a more familiar form of the Froude law, namely, that for dynamic similarity of gravitational effects, the Froude number v^2/xg must be equal for corresponding points in the model and prototype.

For the particular purpose of examining the scaling of such base surge properties as the radius - time curve we use equation (4), noting that corresponding radii R_m and R_p would occur at corresponding times t_m and t_p. If we select the column diameters D_m and D_p as measures of the linear scale, certain radii would correspond to each other if $\frac{R_m}{D_m} = \frac{R_p}{D_p}$. The corresponding time intervals measured from a common zero would have to satisfy the condition of equation (4):

$$\frac{t_m}{D_m^{\ 1/2}} = \frac{t_p}{D_p^{\ 1/2}}$$

Thus, if gravitational forces are dominant and Froude scaling is satisfied, all model and prototype results would fall on the same curve if plotted in the form of r vs τ, where $r = R/D$ and $\tau = t/D^{1/2}$.

3. Model Laws for the Base Surge. We now consider the base surge phenomenon itself in more detail, taking into account the effects of column height, column density, ambient density, etc. It is assumed that, at least in the initial stages, gravitational effects are dominant. Consider a column of height C, diameter D, and density ρ, surrounded by a fluid medium of density ρ_0, and descending under the influence of gravity.

At a height y the material of the column would have a potential energy per unit volume $(\rho - \rho_0)\, g\, y$. The velocity which would be acquired at the base by virtue of this change in potential would be given by $1/2\, \rho\, v^2$. Thus taking a ratio of model to prototype:

$$\rho_r\, v_r^{\,2} = \rho_r \frac{\left(1 - \frac{\rho_{om}}{\rho_m}\right)}{\left(1 - \frac{\rho_{op}}{\rho_p}\right)}\; g_r\, y_r$$

$$v_r^{\,2} = \sigma_r g_r y_r \tag{7}$$

where

$$\sigma \equiv \left(1 - \frac{\rho_o}{\rho}\right)$$

and y_r is the vertical length scale defined by C_m/Cp.

Thus for motion in the vertical direction:

$$\frac{y_r^{\,2}}{t_{ry}^{\,2}} = \sigma_r\, g_r\, y_r$$

and the ratio of homologous time intervals for vertical motion is given by:

$$t_{ry} = \left(\frac{y_r}{\sigma_r g_r}\right)^{1/2} \tag{8}$$

The horizontal and vertical scales are connected by the fact that the velocity v becomes a horizontal velocity at the base of the column. Then for horizontal motion:

$$\frac{x_r^{\,2}}{t_{rx}^{\,2}} = \sigma_r\, g_r\, y_r$$

and

$$t_{rx} = \left(\frac{x_r^{\,2}}{\sigma_r g_r y_r}\right)^{1/2} \tag{9}$$

where t_{rx} is the ratio of homologous time intervals for horizontal motion and x_r is the horizontal scale determined by D_m/D_p.

If we again consider homologous radii in terms of the horizontal scale such that

$$\frac{R_m}{D_m} = \frac{R_p}{D_p}\,,$$

such radii will be attained at time intervals such that

$$\frac{t_{mx}\,(\sigma_m C_m)^{1/2}}{D_m} = \frac{t_{px}(\sigma_p C_p)^{1/2}}{D_p}$$

(g_r is assumed unity).

Thus, measurements of R vs t should fall on the same curve if plotted as r vs τ^*

where $r = R/D$

and $\tau^* = t\,(\sigma C)^{1/2}/D$ (10)

III. CONSTRUCTION OF THE LIQUID MODEL[c]

A simulated base surge phenomenon was produced gravitationally by subsidence and flow of a free column of liquid surrounded by a liquid of lower density. The parameters of the experiment were varied; the numbers given below are only representative of the average dimensions used.

A 15 in. long, 6 in. diameter lucite tube of about 1/32" wall thickness was fixed vertically in the center of a tank with glass walls. A circle of 1/4 in. thick rubber sheeting was placed beneath the tube; a circular slit 1/16" deep was used to seal the bottom end. The rubber was cemented in a circular recess in the tank bottom so that it was flush with the bottom. The bottom of the tank was smooth and carefully levelled. The cylinders were in many cases provided with a concentric inner core of water. This was held in place by a 4 in. diameter lucite cylinder rigidly attached at the top to the outer cylinder and removed simultaneously with the outer cylinder. This arrangement was intended to simulate the hollow core believed to have been present in the CROSSROADS Baker shot.

The dense liquid was prepared by dissolving lead acetate and lead nitrate in water. Because of the "salt effect" more of each salt can be dissolved in the mixture than in pure water. Density ratios as high as 2.25 were achieved. A small amount of ferric nitrate was added to the solution to increase the photographic contrast.

The tube was partially filled with the dense solution and the tank simultaneously filled with clear water to the same level. A 35-mm Mitchell motion picture camera was started running at 100

c. This material is excerpted from References (1) and (5)

frames/sec. and the lucite cylinder was suddenly jerked upwards. The photographs were taken in profile; i.e., with back-lighting (see Figure 2); a few were taken from above (Figure 3).

IV. PRODUCTION OF THE BASE SURGE BY A LIQUID MODEL[d]

by

A. B. Arons, Amherst College,
G. A. Young and Mary L. Milligan

In the experiments performed to date, certain parameters of the initial liquid column have been systematically varied, as shown in Table I, and the radial propagation and height of the resulting model surge have been measured.

Using the results of these experiments, a somewhat more detailed analysis of certain aspects of the model surge has been achieved and is described below.

1. Application of Scaling Law to Liquid Models. The data for radial propagation originally reported in Reference (1), together with additional results obtained in the interim, are shown plotted in Figure 4, in accordance with the scaling criteria developed in Section II above. Figure 4 has been obtained in the following manner:

(a) The origin of time is carefully selected on each separate motion picture record as the instant at which the surge emerges at the base of the column. This is done by plotting the initial portion of the r vs τ^* curve against an arbitrary time scale measured relative to a particular frame and extrapolating the curve to find the time at which $r = 0.5$, this time being taken as the actual origin for τ^*. This provides a more reproducible and satisfactory zero time than the earlier one which was taken as the instant of raising the cylinder (Reference 1). The time origin of the Baker curve, with which these results are subsequently compared, has been selected in the same way.

(b) Measured points from individual experiments made under identical conditions are plotted, and a smooth average curve (composite) is drawn through the experimental points.

Figure 4 yields the following information:

d. This section is taken from Reference (6).

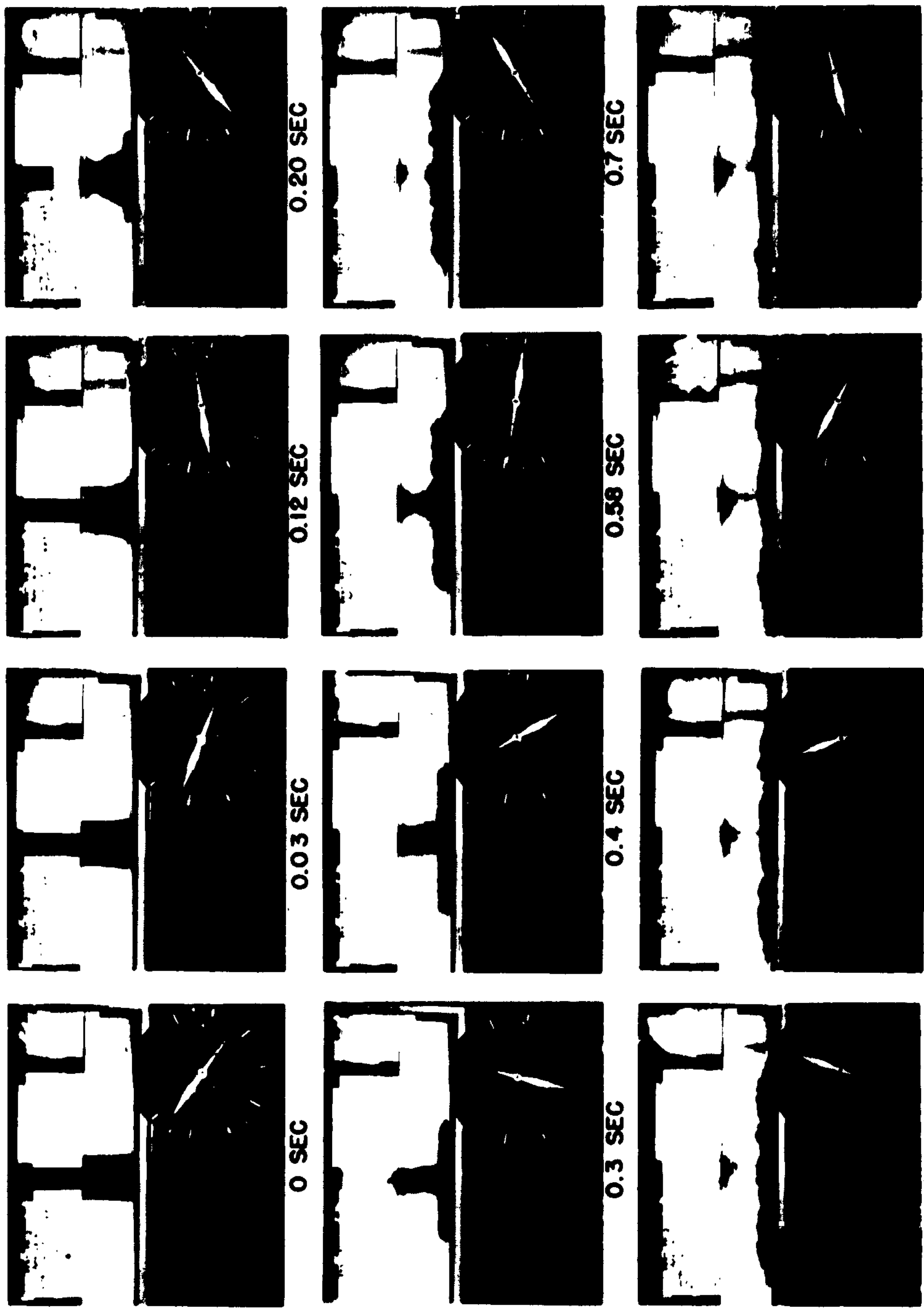
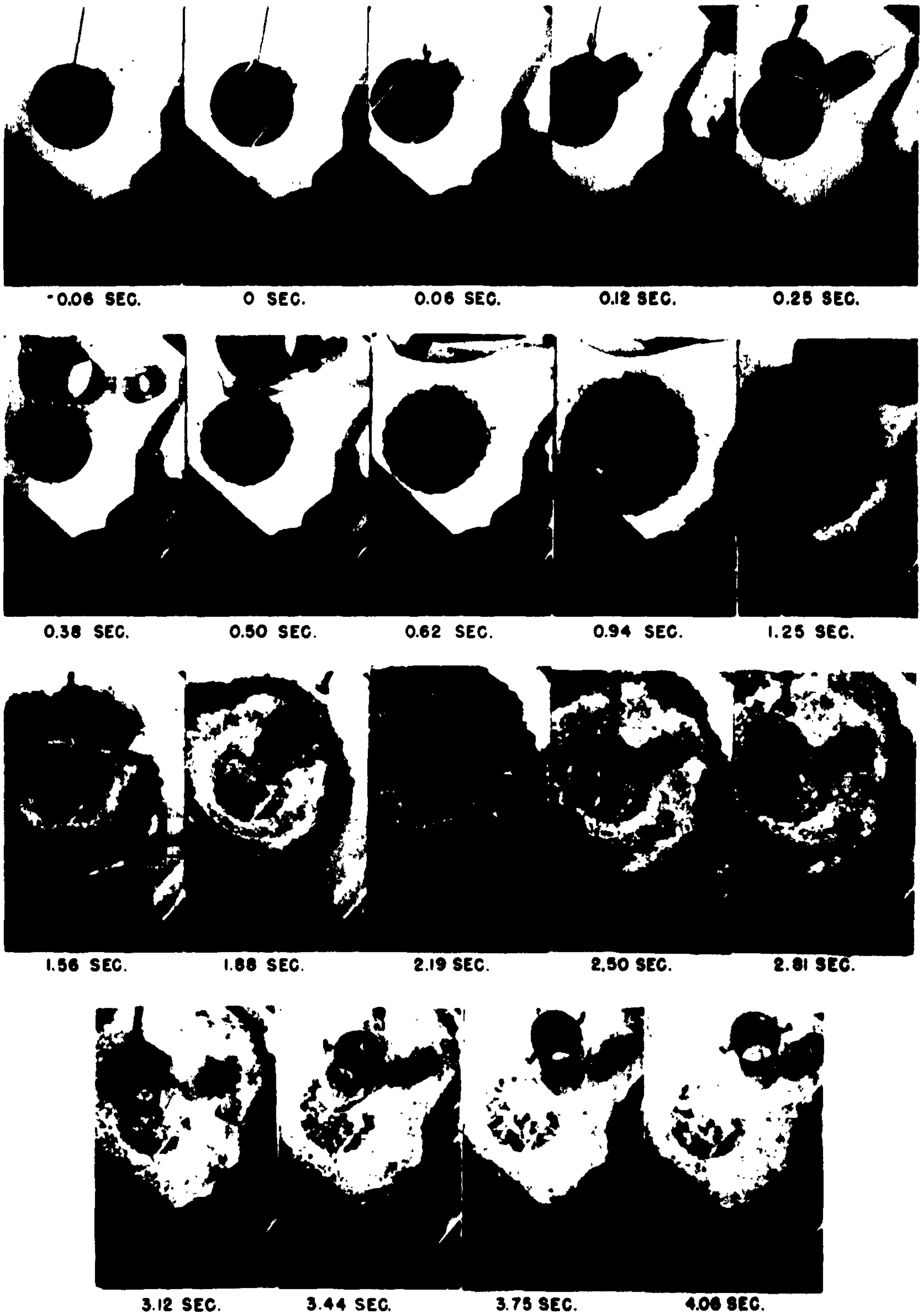


FIG.2 LIQUID MODEL OF BASE SURGE

SOLUTION DENSITY 2.15 — COLUMN HEIGHT 6 IN.

OUTER COLUMN DIAMETER 6 IN. — CLOCK MAKES 1 REVOLUTION/SEC

CONCENTRIC WATER CORE DIAMETER 2.75 IN.



SOLUTION DENSITY 1.75 GM/CC — COLUMN HEIGHT 6 IN.
OUTER COLUMN DIAMETER 6 IN. — NO CORE
DIAMETER OF RUBBER DISC 14.1 IN.

FIG. 3 LIQUID MODEL OF BASE SURGE IN VERTICAL OBLIQUE PHOTOGRAPHS

TABLE I

COLUMN PARAMETERS USED IN LIQUID MODEL EXPERIMENTS
(Specific gravity of ambient liquid: 1.00)

Specific gravity, ρ	Column diameter, D (in.)	Column height, C (in.)	Water core diameter, D_c (in.)	$\frac{D_c}{D}$
2.24	6	6	0	0
2.24	6	9	0	0
2.24	6	12	0	0
2.19	9	6	0	0
2.24	6	6	4.0	0.67
2.24	6	6	4.0	0.67
2.24	6	12	4.0	0.67
2.18	9	6	6.3	0.70
2.22	8.8	9	7.5	0.85
1.75	6	6	0	0
1.75	6	9	0	0
1.75	6	12	0	0
1.75	6	6	4.0	0.67
1.75	6	9	4.0	0.67
1.75	6	12	4.0	0.67
1.75	8.8	9	7.5	0.85
1.25	6	6	0	0
1.25	6	9	0	0
1.25	6	12	0	0
1.25	6	6	4.0	0.67
1.25	6	9	4.0	0.67
1.25	6	12	4.0	0.67
1.25	8.8	9	7.5	0.85

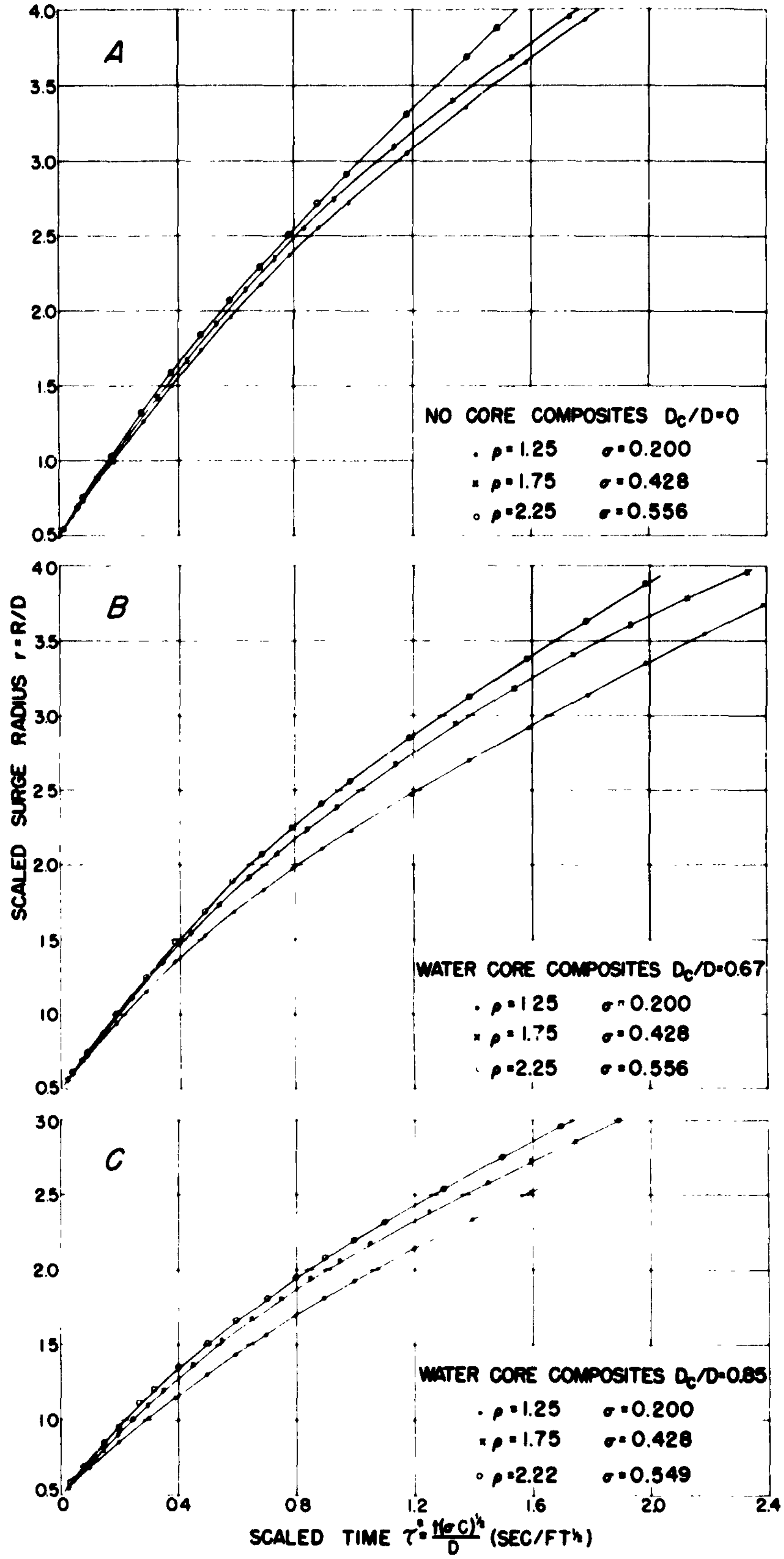


FIG. 4 SCALED SURGE RADIUS VS SCALED TIME FROM LIQUID MODEL STUDIES

(a) Within the range of parameters investigated, variations in the radial propagation, due to changes in column height and diameter, scale in accordance with the criterion of equation (10) for an given σ and proportion of water core (D_c/D); i.e., for each combination of σ and D_c/D there is a separate r vs τ^* curve embracing the effects of variation of C and D.

(b) In general, the curves have very nearly the same limiting slope as $\tau^* \longrightarrow 0$, with the possible exception of the few low density, thin-walled columns.

(c) The r vs τ^* curves show lower slope and stronger downward curvature with decreasing ρ (or σ) and increasing proportion of water core, D_c/D.

2. Interpretation of Results. It is evident from the above results that the generalized Froude scaling criterion (equations (9) and (10)) accounts for the scaling of the initial radial surge velocity over the range of parameters shown in Table I. In the subsequent flow, however, this criterion scales only the effects of column height and column diameter and fails to account for the influence of the density. (No attempt has been made to introduce the effect of the water core explicitly into the scaling criteria, and different curves for different values of D_c/D are to be expected.)

Our tentative interpretation of these observations is the following:

(a) Within the range of the observations which have been made, gravitational and inertial forces play the dominant role in establishing the character of the flow.

(b) Resistive forces probably become apparent principally through their influence on the shape of the head of the surge. It seems reasonable to expect the density difference to be the most sensitive parameter in this regard and to be most influential in establishing the shape of the head.

(c) For a given density difference, the effects of varying C and D over a reasonable range would then be accounted for by Froude scaling since the resistive effects are probably relatively insensitive to changes in these parameters.

A different curve, however, would be obtained for each σ.

As indicated above, these interpretations are tentative, and more detailed understanding of the nature of transient density flows of this type is essential before definite conclusions are to be drawn.

3. Scaling of Surge Height. No satisfactorily rationalized scaling law for the height H of the liquid model surge has been devised. Using either C or D alone as scale factors for H fails to produce a common h vs τ^* curve for the various experiments. It has been discovered empirically, however, that, within the normally large scatter of measurements of this parameter, a common h vs τ^* curve could be obtained for each of the D_c/D families by using as a length scale the geometric mean of D and C and defining: $h = H/\sqrt{DC}$

Figure 5 shows h vs τ^* plots for the various values of D_c/D. It will be noted that, within the scatter of the observations, the experimental points may be regarded as lying on the same curve for any given proportion of water core. The maximum value of h attained by the surge decreases with increasing proportion of water core (increasing ratio D_c/D).

V. COMPARISON OF LIQUID MODEL RESULTS WITH CROSSROADS BAKER[e]

by

A. B. Arons, Amherst College,
G. A. Young and Mary L. Milligan

1. Scaling of Effective Column Height. It was noted in Reference (5) that when scaled radius r is plotted against τ for the base surge observed in shallow chemical explosions fired under conditions geometrically similar to those of Shot Baker, all the points fall on the same initial curve regardless of charge size. One might have expected, a priori, that the effective column height would not scale in the same way as column diameter, and that experimental points would fall on curves having the same initial slope only if r were plotted against τ^*, taking into account the effect of the distorted length scale. It was remarked in Reference (5), on the basis of very fragmentary evidence, that the interpretation must be made that the effective column height in underwater explosions (i.e., the height determining the dynamics of the spread of the surge) must scale very nearly as the cube root of the charge weight and directly as the column diameter. This view is now strongly supported by the liquid model results described above, and the further inference follows that substantial quantities of the water projected into the air by the explosion do not contribute

e. This section is taken from Reference (6).

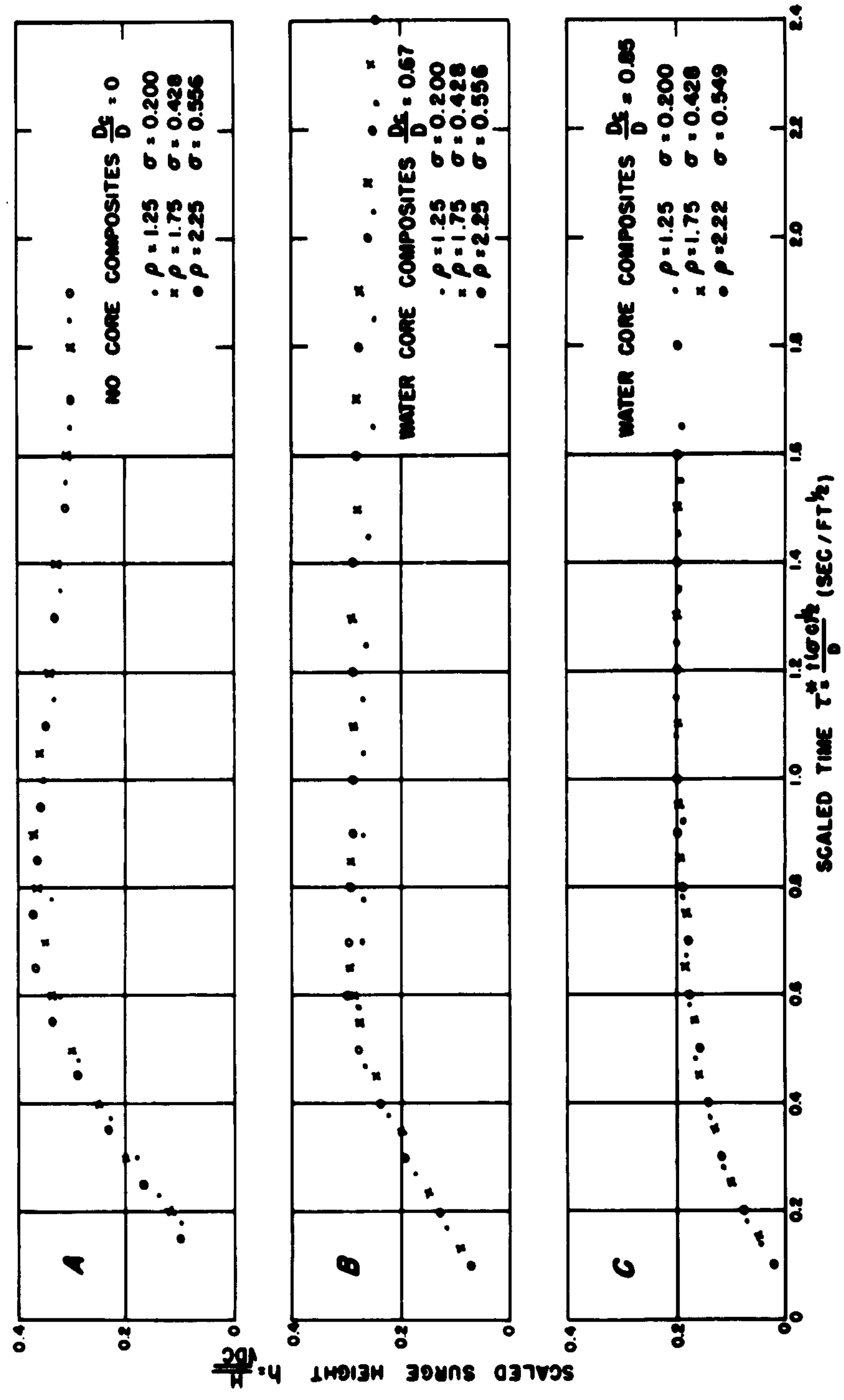


FIG. 5

SCALED SURGE HEIGHT VS SCALED TIME FROM LIQUID MODEL STUDIES

to the formation of the propagating surge cloud but fall out, remain airborne, or evaporate without participating directly in the dynamics of the base surge.

2. Comparison of Liquid Model Results with Baker Surge Height Data. Owing to the scatter of measurements of the height of the Baker surge cloud, it is difficult to establish a meaningful comparison between these observations and the liquid model results. To indicate at least roughly the nature of the data, Baker surge height results (scaled in the manner used in the liquid models) are shown plotted in Figure 6 superposed on the smoothed curve for the $D_c/D = 0.67$ water core models. The Baker effective column height is arbitrarily taken as about 3500 ft and $(\sigma\ C/D)^{1/2} = 0.77$ is used to determine the relation between τ and τ^*. Within the obviously wide scatter of the measurements for both Baker and the liquid models, the results are in good agreement over the initial time interval $0 < \tau^* < 0.8$. The apparent Baker surge height continues to rise subsequently, probably due to condensation in the layers of air lifted from the surface of the lagoon - a process previously postulated by these authors and others.

3. Comparison of Liquid Model Results with Baker Surge Radial Propagation Data. The question now arises as to whether or not the initial portion of the r vs τ curve observed in underwater explosions can be compared with the r vs τ^* curves of the liquid models in such a way as to obtain information regarding the value of $(\sigma\ C/D)^{1/2}$ which applies to the explosion-produced columns. With this object in mind, the average surge radius-time curve[f] is shown plotted in Figure 7 for various assumed values of $(\sigma\ C/D)^{1/2}$, and the resulting curves are superposed on the liquid model results.

Examination of Figure 7 indicates that the general shape of the explosion-surge curve is in best agreement with liquid models having a water core ratio, D_c/D of about 0.7. Liquid models without core show essentially the same initial slope but continue to rise much more steeply than the explosion curve, whereas liquid models with a water core ratio D_c/D of 0.85 show too strong a downward curvature.

With reference to Figure 7b, it is evident that using a value of $(\sigma\ C/D)^{1/2}$ less than about 0.77 would cause the explosion curve to have too high an initial slope, whereas taking a value greater than about 0.88 would give it too low an initial slope and too strong a downward curvature.

On the basis of this comparison, it is tentatively assumed that explosion-produced columns behave as though they had cores

f. Since the observations with scaled explosive charges all fall on the initial portion of the Baker r vs τ curve, this curve is used as the basis for comparison in Figure 7.

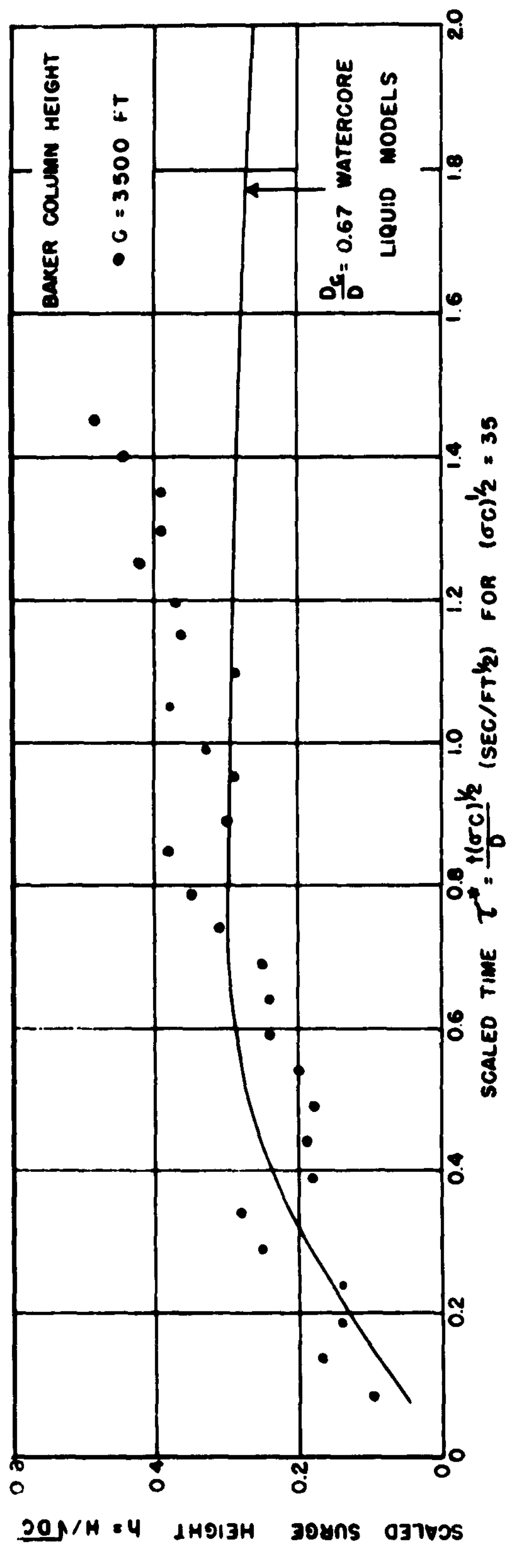


FIG. 6
COMPARISON OF BAKER SCALED HEIGHT VS
SCALED TIME CURVE WITH LIQUID MODEL RESULTS

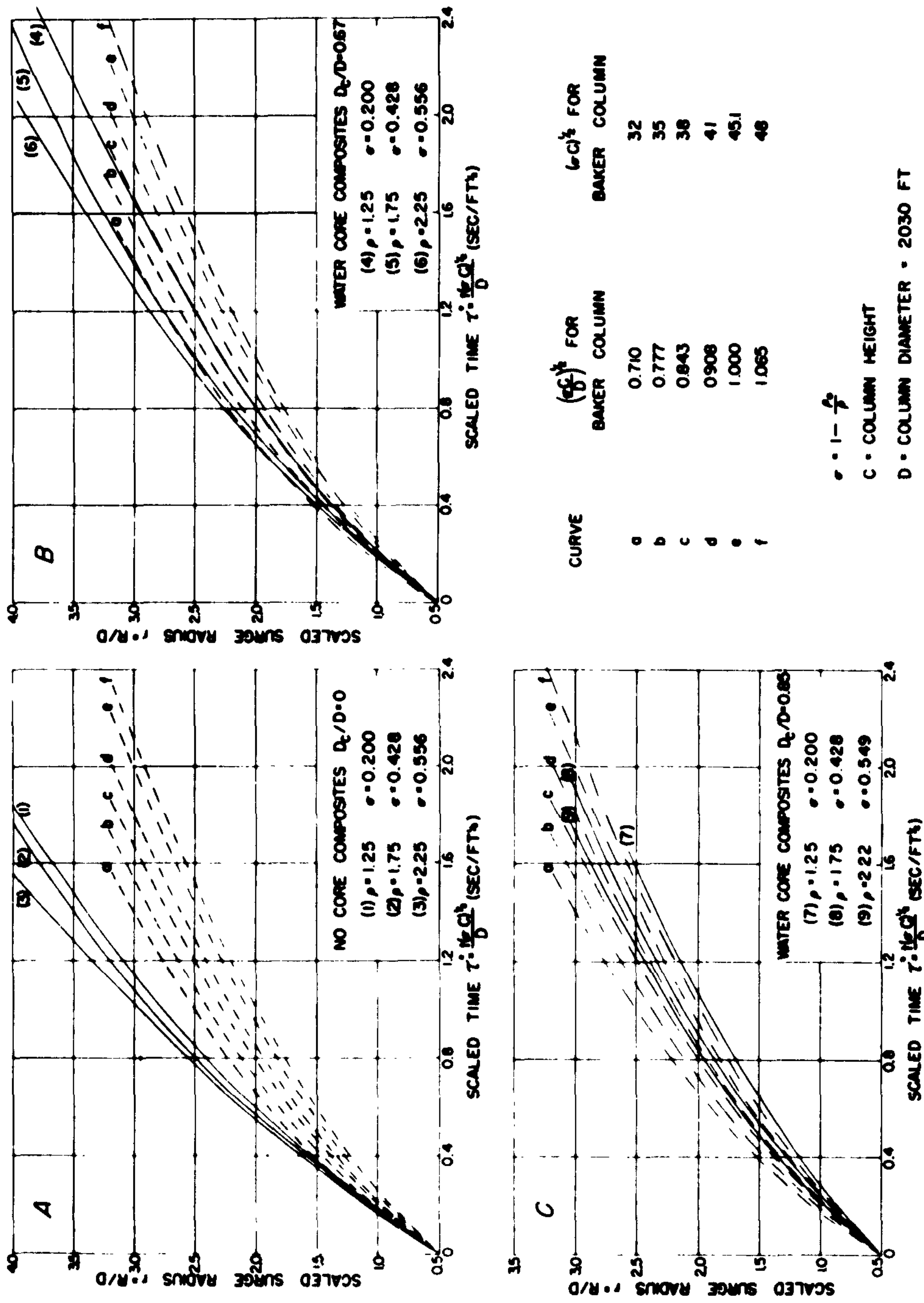


FIG. 7
COMPARISON OF BAKER SCALED RADIUS VS SCALED TIME CURVES WITH LIQUID MODEL RESULTS

of the order $D_c/D = 0.7$ which do not contribute to propagation of the surge cloud and that the appropriate values of $(\sigma\, C/D)^{1/2}$ lie somewhere in the range between 0.77 and 0.88. Since $D^{1/2} = 45.1$ for Baker, the corresponding values of $(\sigma C)^{1/2}$ for the Baker column lie between 35 and 39.

To illustrate the specific application of the above results to the Baker column, Figure 8 shows a plot of C vs ρ/ρ_0 for two values of $(\sigma C)^{1/2}$, and a region showing a rough estimate as to the possible combinations of ρ and C is indicated. An upper boundary is set by the fact than an effective column height in excess of about 4000 ft is inadmissible, and comparison with Figure 7b indicates that a selection of ρ/ρ_0 greater than about 2 is not logical.

Also on comparison with Figure 7b, it is seen that good agreement is to be expected between an explosion curve having $(\sigma C)^{1/2} = 35$ and a hypothetical liquid model curve for a ρ/ρ_0 of about 1.4 to 1.6. Using this observation, a strongly shaded region is shown in Figure 8, indicating our present best estimate as to the ρ and C of the Baker column. For a core $D_c/D = 0.7$, and assuming an ambient air density of 0.075 lb/cu.ft., this indicates the presence of about 100,000 to 130,000 tons of water in that part of the column contributing to the formation of the Baker surge.

Since the effects of the core and the density difference upon the propagation of the surge are not clearly understood, the fundamental assumption of the above treatment (namely, that the liquid model and explosion results are comparable to the extent implied) is rather tenuous, but represents the best guess available at the present time.

4. Source of Shot Baker Data. The Baker data[g] used in the above discussions were taken directly from the University of California report on Photogrammetry of Test Baker (Reference 7). The column diameter was taken as 2030 ft.

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g. These data are also given in "Effects of Atomic Weapons", August 1950, p. 107.

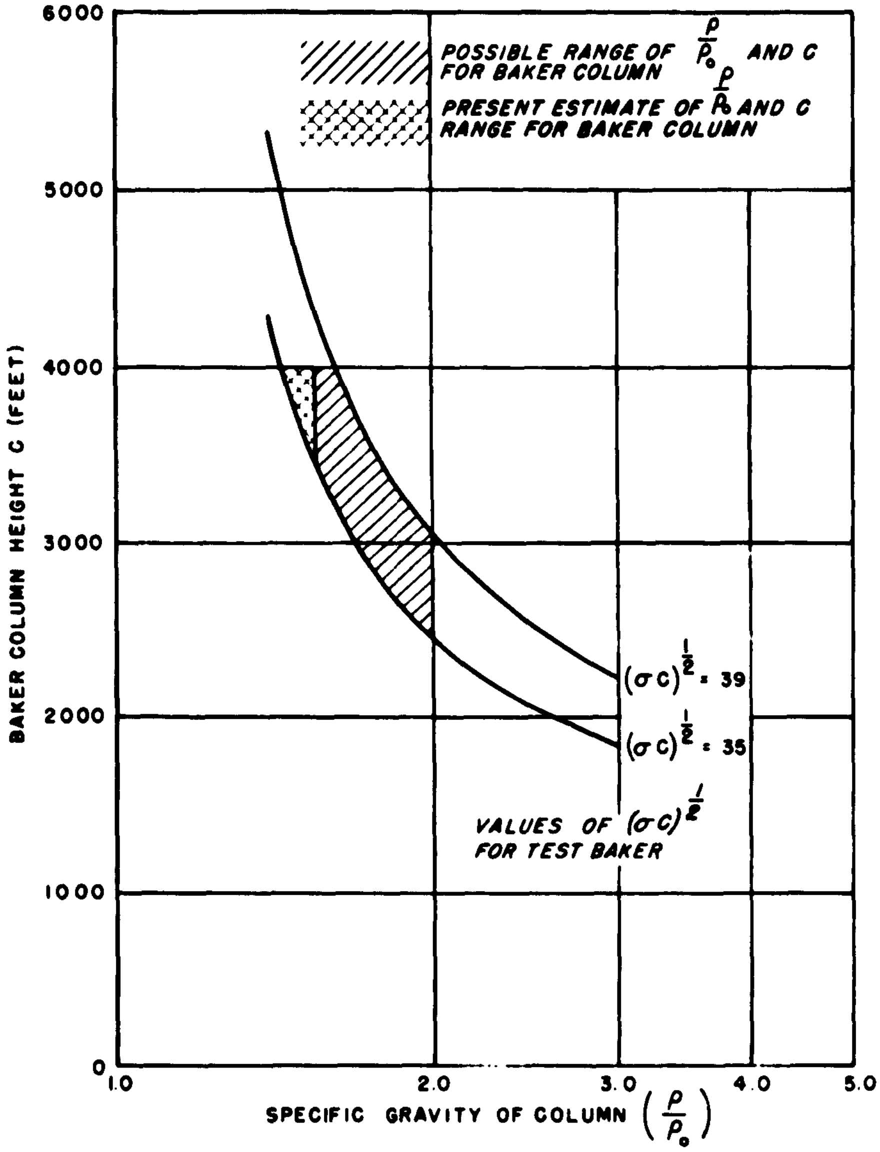

FIG. 8

PROBABLE RANGE OF DENSITY
AND COLUMN HEIGHT FOR TEST BAKER

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Liquid	LIQU	Comparison	CMRI		
Model	MODE	Crossroads	CROR		
Base	BASE	Baker	BAKR		
Surge	SURG	Height	HEIG		
Simulation	SIMU	Density	DENS		
Motion	MOTI	Column	COLU		
Shallow	SHAL	Mechanism	MECH		
Underwater	UNDE				
Explosion	EXPS				
Scaling	SCAL				
Laws	LAWA				
Water	WATR				

PRNC-NOL-5070/28 (5-62)

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 62-191)
LIQUID MODEL STUDIES OF THE BASE SURGE (U), by E. Swift, Jr. 1 Oct. 1962. 22p. Task NOL-152. UNCLASSIFIED

When a constrained column of dense liquid standing on bottom of tank of water is released suddenly, it sinks and flows outward radially along bottom. This action simulates early motion of base surge from shallow underwater explosions. Such liquid model experiments are described, scaling laws are derived, and comparisons with CROSSROADS Baker are made. It is estimated that between 100,000 and 130,000 tons of water in Baker column contributed to surge, that column height was between 3500 and 4000 feet, and that column density was between 1.4 and 1.6 times that of air.

1. Explosions, Underwater
2. Explosions - Shallow water
3. Base surge - Simulation
4. Operation Crossroads

I. Title
II. Swift, Elijah, Jr.
III. Project

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